EXHIBIT A.521

(9 of 17)

These challenges all exist for the management of the Mountain and Gaza Aquifers. These aquifers underlie Palestinian and Israeli territory, necessitating cooperation to successfully manage the resource. Water is pumped from hundreds of wells owned by individual property owners and municipalities. Finally, aquifer over-pumping has led to the extraction of more groundwater than is replenished.

Overpumping or "groundwater mining" can have several negative consequences. As the water table falls, water must be lifted (i.e., pumped) a greater vertical distance, thus requiring more electricity and possibly larger pumps. Depending on geologic features, the aquifer may also become completely exhausted. As aquifers are depleted they can subside, leading to permanent loss of aquifer storage capacity. In the case of the Coastal Aquifer, seawater may enter an aquifer as the water table drops, decreasing its quality. Termed "saltwater intrusion," this contamination is costly to reverse.

Water Quality. A related and progressively worsening problem is deteriorating water quality. Surface water is contaminated through the release of untreated sewage, industrial effluence, and agricultural runoff. This polluted surface water then percolates into the aquifers, leading to groundwater contamination. In water-scarce regions without proper water treatment facilities, consumption of polluted water leads to significant heath complications.

All natural systems can accommodate some contamination, but as industrial, household, and agricultural uses of water grow, pollution loads in surface waters increase as the remaining flows diminish in response to increased withdrawals. As a result, increasingly large levels of pollutants are discharged into ever-smaller quantities of water. These problems become particularly serious when urban water supplies and waste grow faster than sanitation infrastructures. As surface water quality and quantity decrease, groundwater extractions increase, further exacerbating groundwater overuse.

Groundwater quality problems in the West Bank and Gaza are also significant. Although no water quality database exists, individual studies and monitoring projects indicate severe contamination and water quality problems in all major aquifers. In half of the wells in Gaza, chloride and nitrate levels significantly exceed World Health Organization (WHO) standards for drinking levels.[3] Aquifers in both Gaza and the West Bank have elevated levels of heavy metals and high chemical oxygen demand/biochemical oxygen demand ratios, indicating the presence of non-biodegradable industrial contaminants (METAP, 2001). Intestinal parasites have been found in Lake Tiberias and the Jordan River.

Water and Waste Infrastructure. Although much has been accomplished in providing access to improved water supply and sanitation facilities, many people still lack adequate access to safe drinking water and sanitation. Many people in the Middle East without access to water supplies live in rural areas; however, many residents of poor urban neighborhoods in the West Bank and Gaza also lack access to adequate water

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[3] Chloride levels exceed 1,000 milligrams per liter (mg/l), and nitrate levels exceed 290 mg/l. The WHO drinking water standard for chloride and nitrate is 250 mg/l and 50 mg/l, respectively.

supplies from piped connections or standpipes. Water supply in many cities is intermittent, with lengthy intervals of no water service. Residents without connections are forced to rely on water delivery.

As in many other developing countries, sanitation tends to receive less attention and fewer financial resources than water supply. The intrusion of raw sewage into ground and surface waters and agricultural reuse of insufficiently treated wastewater have negative environmental and health impacts. Wastewater needs to be adequately treated, regardless of whether it is reused, to avoid degradation of water sources and adverse health effects.

Practically all countries of the region reuse at least some of their wastewater (although reuse in the West Bank and Gaza is limited). In some countries—especially in Saudi Arabia, the Gulf countries, and Israel—a substantial share of the water supplied for municipal and industrial uses is reused in agriculture after treatment.

Links to Agriculture. The agricultural sector is both the leading consumer of water and a major source of water pollution in the Middle East. Irrigated agriculture accounts for 60 to over 80 percent of water use (Saghir, Schiffler, and Woldu, 2000). Therefore, agricultural policy directly affects water demand and consumption. In nearly all countries in the region, public irrigation agencies provide farmers with water at subsidized tariffs. The economic value of water in municipal and industrial uses is many times higher than in agriculture. Irrigated agriculture contributes 5 to 10 percent to GDP in most countries, while industry contributes 20–50 percent to GDP; the service sector, which is concentrated in urban areas, contributes another 30–50 percent. While, on average, irrigation accounts for 7–8 times more water use than do municipal activities, it contributes 4 to almost 20 times less to GDP than do urban industry and services.

Due to heavy reliance on fertilizers and pesticides, agricultural runoff is a significant source of water pollution. Agricultural runoff can lead to nutrient overload and increased salinity in irrigated areas. Salinization reduces yields, decreases soil moisture, and increases susceptibility to erosion. The end result is desertification.

Links to Energy. Worldwide, the Middle East is often viewed as the world's primary supplier of energy. However, the Middle East is also a large and rapidly growing consumer of energy. As with water resources, the countries of the Middle East vary in terms of their domestic energy resources. Many—but not all—have extensive oil and gas reserves. Energy is expensive in countries such as Jordan, Syria, Israel, Egypt, and other North African countries. As a result, the majority of the Middle East's population already faces high energy prices and energy shortages. Since population growth continues to outpace expansion of the energy infrastructure, the region's energy problems are likely to worsen in coming years. The recent discovery of natural gas reserves offshore in the Mediterranean Sea, however, could reduce this energy limitation for Israel and Palestine. Current estimates suggest that Israel and Gaza may have access to 3.5 trillion cubic feet of natural gas reserves off the coast (EIA, 2003b). These reserves could significantly reduce the cost of desalination by lowering energy prices in the region.

Many aspects of water distribution and use are energy intensive. First, water must be procured—water obtained from wells must be pumped to the surface. Next, water must be delivered to demand centers. Although most long-distance water conveyance systems rely on gravity, the water often must be pumped up and over mountain ranges or out of valleys, using much energy. The water also must be treated prior to delivery to end users if the water source is degraded. Tertiary treatments, such as ultraviolet radiation and ozonization, are very energy intensive. Finally, almost all water delivered for domestic and industrial use becomes sewage and must be treated prior to reuse or disposal. Energy requirements for such treatment are considerable.

Israel exemplifies the importance of energy in production and use of water. In 1992 about 9 percent of Israel's electricity was used for water needs.[4] A significant portion of this total is needed to pump water from Lake Tiberias, over a mountain range, and into Israel's National Water Carrier. This requires continuously moving 1.37 MCM of water more than 400 meters vertically each day. Israel's agricultural sector consumes an additional 4.6 percent of the nation's electricity, a large portion of which is used for groundwater pumping and irrigation. Finally, a portion of industrial, commercial, and household electricity consumption is used for groundwater pumping. It is possible that well over 15 percent of Israel's electrical generation capacity (approximately 1,000 megawatts) is used for water, not including treatment of drinking water or wastewater.

Currently, the water system in the West Bank and Gaza is not very energy intensive. Leading proposals for increasing the water supply, such as desalination and wastewater treatment and reuse, however, are highly energy intensive. Ensuring adequate water supplies in the region will require investments not only in new water sources, but also in an expanded electric power infrastructure. Since the vast majority of energy consumed by Palestinians is imported, increases in energy consumption by the water sector will directly affect energy imports, the cost of energy, and ultimately the economy.

Water Issues in Israel and Palestine: The Past and Present

Water issues in the region have been frequently studied, and many such studies have highlighted the vital role that water supply solutions may play in the peace process. Creating a viable Palestinian state will require settling water disputes and ensuring access to adequate amounts of clean water for both Israelis and Palestinians.

Historical Context

Securing adequate water supplies has been an important issue in the region throughout both ancient and recent history. In the last 50 years, the enduring problems resulting

[4] Personal communication with Alvin Newman, April 3, 2003.

from the region's water scarcity have been exacerbated by the region's political disputes. The main water issues in the 1950s included: water quotas affecting Israel, Syria, Lebanon, and Jordan; the use of Lake Tiberias for storage; the use of surface water, particularly the Jordan waters and the Litani River (in Lebanon); water importation from the Mediterranean Sea; and the nature of international participation in the region's water use disputes and agreements. These issues continue to drive much of the dialogue surrounding water in the region.

Unilateral water development by every party in the region led to a crisis at the end of the 1960s. After creation of the Israeli state, Israel, Syria, Egypt, the United Nations, and the United States made many attempts to develop a multilateral water management plan among the countries in the region. In 1955, however, the most prominent of these plans (the Unified, or Johnston, Plan) collapsed (Isaac, 1999; PASSIA, 2003). After its failure, unilateral water development and conflicting attempts to divert the Jordan River were followed by military clashes in 1967 (Zahra, 2000).

In the wake of the 1967 Six-Day War, the water conflicts continued. Israel's control of water resources was strengthened, and the Palestinians, as a result of the Israeli's increased control, had access to diminishing amounts of clean water. At this time, the Palestine Liberation Organization began attacking the water infrastructure in the Israeli settlements, and Israel attacked the East Ghor Canal, a part of the Unified Plan that would have supplied 250 MCM/yr to Palestinians. Israel then transferred water authority to the military and took control of the water resources in the area. Palestinian use was restricted to Israeli-established quotas, and Israel forbade unlicensed construction of new water infrastructure.

Agreements made in the early 1990s established the basis for much of the current dialogue surrounding water issues in the region. In 1992, the second round of peace talks resulted in the creation of the water resources working group. This was a step forward; however, the parties were wary of entering into technical agreements in the absence of a political settlement of core issues. In 1993, Oslo I made some progress on water issues. The Declaration of Principles recognized the need for cooperation in managing and developing water resources and allowed the Palestinians to drill new wells, subject to Israeli approval.

Oslo II (the Taba Agreement) strengthened cooperation but produced no tangible changes in the Palestinian water situation. However, in an important move forward, Israel recognized Palestinian water rights in the West Bank for the first time in 1995. The Taba Agreement was supposed to establish future allocation based on "prior use," restricting the Palestinians' agricultural use to only slight growth above about 100 MCM per year. Although the agreement stipulated the development of new water resources and arranged for immediate domestic water needs of roughly 24 MCM per year for the West Bank and roughly 5 MCM per year for Gaza, this quantity represented only roughly 40 percent of the agreed-upon need. Furthermore, remaining water issues were reserved for final status negotiations. These final status negotiations never occurred,

and not all of the agreed-upon quantity has been released. Because these issues have not been resolved, Israel continues to consume according to historical use, and the West Bank and Gaza are unable to support their increasing needs.

Current Situation

Palestinian Water Management. The Palestinian Water Authority (PWA) and the National Water Council (NWC) are in charge of implementing any water management strategy. The PWA assumed responsibility as the central water authority within the context of the peace process in 1995. It is responsible for strategic planning, monitoring and oversight, policy implementation, regulation, and water rights negotiations. Its main goal is to ensure the equitable utilization and sustainable management and development of Palestinian water resources. The local ministries, utilities, and water users' associations are responsible for the actual implementation of the PWA's national water plan.

While the PWA is effectively the primary water agency, the NWC is officially the highest body within the Palestinian Authority regarding water issues. The NWC, established in 1996 and chaired by the president of the PA, is composed of the ministers of the five key PA ministries and water experts. Although the NWC has never been convened, it is formally responsible for setting the water policy—defining and endorsing the vision, strategy, and policies for the water sector.

Water Sources. The main sources of water for the West Bank, Gaza, and Israel include groundwater from two main aquifers (Mountain and Coastal) and various springs, as well as surface water from the tributaries of the Jordan River and Lake Tiberias (see Figure 6.2). The Mountain Aquifer is divided into three aquifer basins: Western, Northeastern, and Eastern. The Gaza Aquifer is a subset of the Coastal Aquifer.

Israel's water supply is diverse. Israel obtains water from several aquifers (Mountain, Coastal, Galilee, and Negev) and the Jordan River. It also recycles a substantial amount of wastewater for irrigation. Lake Tiberias is used as Israel's major surface storage, containing roughly 4,000 MCM (National Research Council, 1999). In addition, Israel recently signed an agreement to purchase water from a desalination plant to meet its expected water needs in the future. This plant will produce 100 MCM per year, meeting about 5 percent of Israeli water demands. The expectation of the desalination plant developers is that a power plant, fueled by natural gas, would be built to power the desalination plant.

In contrast, Palestinian water sources are less diverse and severely limited. The West Bank obtains most of its water from the Mountain Aquifers, some from Israel, and some from springs. Gaza's supply comes predominantly from the Gaza Aquifer, with a small supply from Israel. Table 6.1 shows the sustainable water resources (excluding desalination and imports from other regions) and their use by the Palestinians and the Israelis. The "Remaining" water resources are those that could provide new supplies. Negative remaining resources indicated unsustainable use.

Table 6.1
Sustainable and Currently Used Water Resources in the West Bank and Gaza

Resource	Sustainable	Palestinian	Israeli	Remaining
Groundwater				
Western	181	21.4	343.1	–183.5
Northeastern	72.5	15.8	64	–7.3
Eastern	86	25	46.3	14.7
Gaza	55	110	10	–65
Spring flow				
Western	1.2	2.4	N.A.	–1.2
Northeastern	8.4	16.8	N.A.	–8.4
Eastern	49.9	44.8	55	–49.9
Surface water				
Jordan River	120	0	120	0
Wadi flow	168.9	0	N.A.	168.9
Rainfall	125.8	4.9	N.A.	120.9
Wastewater	114.4	9.2	N.A.	105.2

SOURCE: CH2M HILL, 2002a; PCBS, 2003c; and the Oslo Accords.
NOTES: The data used come from the Palestinian Central Bureau of Statistics. There are disagreements and uncertainty about how much water is being pumped from the aquifers. The Israeli Water Commission estimates that the Palestinians draw as much as 320 MCM/yr. Negative remaining resources indicate unsustainable use. N.A. is not applicable.

Inadequate Supply. Palestinians consume, on average, around 55 liters of water per day (l/d)[5] for domestic purposes, or slightly more than half the WHO standard for minimum consumption of 100 l/d. This average consumption estimate masks significant variability. Some surveys have estimated that as much as 10 percent of the population uses less than 30 l/d (PHG, 2003).

In 2001, only 104 MCM/yr of water was consumed by the Palestinian domestic sector (PCBS, 2003b). Assuming system-wide water losses of about 40 percent,[6] it will take an additional 102 MCM/yr to supply the present Palestinian population of 3.4 million with 100 liters of water per day for domestic uses. Meeting the domestic water needs of a Palestinian population of 5.5 million in 2015 under present-day conditions will require an additional 231 MCM/yr of water.

Agricultural water consumption is important to the Palestinian economy. In 2000–2001, agricultural production in the Palestinian territories exceeded $800 million. Fifty-four percent of this production was from cultivation, and 46 percent was from livestock (PCBS, 2003b). According to the PWA, 64 percent of all groundwater extraction was used for the agricultural sector in 2001. Despite the high agricultural water use, only 13 percent of all cultivated land is irrigated. Table 6.2 provides a sum-

[5] Domestic consumption estimated from Palestinian Central Bureau of Statistics 2003 data (PCBS, 2003b).

[6] CH2M HILL (2002b) estimates current system-wide water losses to be about 40 percent.

Table 6.2
West Bank and Gaza Agricultural Area and Net Water Demand in 2001

	Area[a] (thousands of hectares)			Water Requirement[b] (1,000 CM/hectare)	Net Water Demand (MCM)	Gross Agricultural Demand[c]
	Rain Fed	Irrigation	Total			
Vegetables	4.0	13.4	17.4	5.4	72.0	160
(percentage)	(23%)	(77%)				
Field crops	43.7	2.7	46.4	4.8	12.8	28
(percentage)	(94%)	(6%)				
Fruit trees	107.7	8.2	115.9	11.0	89.8	200
(percentage)	(93%)	(7%)				
Total	155	24	180		175	388

[a] PCBS, 2003a.
[b] ARIJ, 1995 and 1996.
[c] Gross agricultural demand includes 40 percent system losses and 25 percent irrigation application losses.

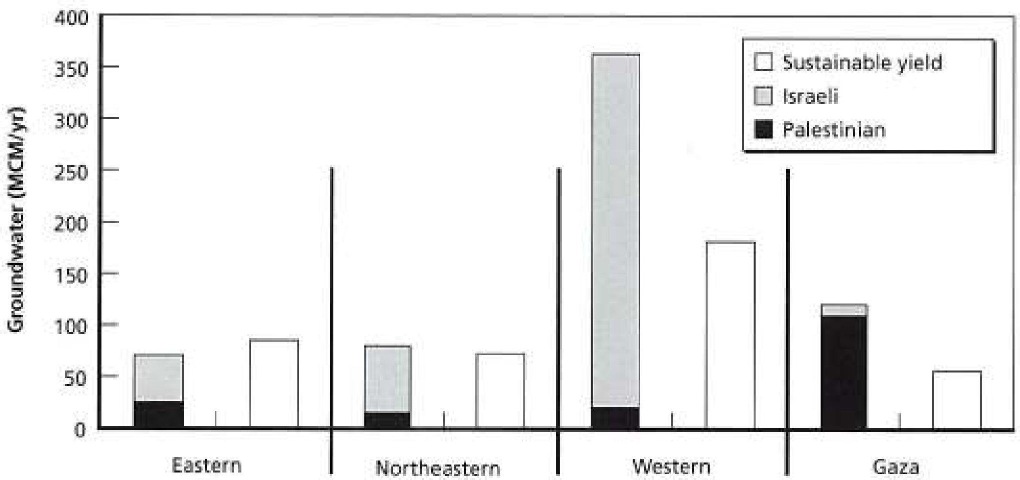
mary of cultivated area and net water requirements by crop type. Fruit trees demand more than half of all water and require more than twice the water per hectare than do vegetables and field crops.

It is estimated that in 2001, because not enough water was available, only 30 percent of irrigation needs were met (CH2M HILL, 2002a). Meeting all current irrigation demand and accommodating growth of irrigated areas will dramatically increase agricultural water demand.

Overuse of Aquifers. There is some disagreement over the sustainable groundwater yields; however, there is little doubt that the Palestinians and Israelis overuse the region's aquifers. The National Academies of Sciences and the studies behind the Oslo Accords estimated that the sustainable yield is equal to the annual rate of recharge and is slightly greater than current use (perhaps as much as 30 MCM/yr for the Mountain Aquifers) (National Research Council, 1999). Recent modeling analysis by CH2M HILL (2002a), however, estimates that the sustainable yields for the Mountain Aquifers are only half the recharge rate—the other half of the recharge is lost to deep percolation and flow out of the basins. We use CH2M HILL's sustainable estimates for the basins of the Mountain Aquifers. As more recent modeling estimates of the Gaza Aquifer do not exist, we use the Oslo recharge value as the sustainable yield. Based on these estimates, all aquifers but the Eastern are in deficit (Figure 6.3). The Gaza and Western Aquifer problems are particularly severe, as use is twice as high as the sustainable yield.

Declining Water Level and Quality. Overuse of the aquifers can cause the water table to fall and springs to dry up. Overuse can also lead to saltwater and wastewater

Figure 6.3
Current Consumption and Sustainable Yields for Major Aquifers



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intrusion, reducing the quality of the groundwater. Based on well measurements, the Coastal and Mountain Aquifers' water levels have declined between 1984 and 1998 (EXACT, 2003). Due to significant precipitation in the early 1990s, this decline began to level off in the latter part of the period (1984–1998). However, the drought of the past few years, together with increased groundwater exploitation, is likely to lead to a return to rapidly declining water levels. In the Gaza Aquifer, the groundwater level has remained relatively stable despite heavy overuse, likely due to saltwater intrusion.

Infiltration of untreated wastewater and intrusion of saltwater have reduced water quality in all of the aquifers in the region. The problems are most acute in the Gaza Aquifer as a result of the shallow depth of the groundwater and the almost complete lack of sanitation infrastructure in Gaza. Because the aquifer is close to the surface, polluted water percolates into the aquifer relatively quickly. Significant elevated nitrate concentrations have been found in most of the test wells, attributed mostly to agriculture fertilizers, manure, and disposal of untreated sewage. Near the coast, an observation well showed a consistent 15 mg/l annual increase in chloride concentration from 1984 through 1998. Wells near agricultural areas have also shown chloride increases, perhaps due to infiltration of irrigation water. Wells south of Gaza City had consistent 45 mg/l yearly increases in chloride concentration from 1984 to 1998. Table 6.3 shows some key measures of water quality in the Gaza Aquifer and compares the level of concentration for these chemicals with acceptable guidelines.

The Mountain Aquifers are also showing signs of stress. For example, some 605 water samples taken from the Mountain Aquifers were recently found to have bacterial contamination (EXACT, 2003). Water from 70 springs around Bethlehem was found to be unfit for human consumption; yet this supply continues to be used by house-

Table 6.3
Water Quality in the Gaza Aquifer (in milligrams per liter)

Dissolved Substance	Gaza Concentration	International Standards for Acceptable Concentrations
Sodium	300–1100	20
Chloride	400–1500	250
Calcium	40–120	36
Sulfate	50–400	250
Magnesium	40–120	30
Bicarbonate	300–700	225
Potassium	6–10	4
Nitrate	40–140	45
Fluoride	0.4–2.9	1.5

SOURCE: WHO as cited in Atwan et al., 1999.

holds (EXACT, 2003). Although the Mountain Aquifers do not suffer from seawater intrusion, all aquifers in the region are contaminated with untreated wastewater. The Mountain Aquifers have seen increases in chloride concentrations; in the Northeastern Aquifer sections, concentration has increased at a rate as high as 19 mg/l annually, mostly because of the influences of irrigation and untreated sewage. Concentrations increased significantly during periods of heavy rain in 1992 and 1993, suggesting increased leaching of salts from the soil (EXACT, 2003).

Recent upgrades in the Gaza water supply system were completed through a World Bank project that permitted the Palestine Water Authority to outsource management and operations to a private company. As a result, almost all water for domestic use is treated before consumption. Although treatment helps to reduce chemical concentrations, according to the PWA, the water consumed still does not achieve internationally acceptable levels of quality (see Table 6.3).

The quality of water used for irrigation can also significantly affect crop production. As discussed above, use of fertilizer and pesticides can significantly degrade water and soil quality. As increasingly brackish water is used for irrigation, the soil becomes more saline. Increased salinity can reduce crop yields. In addition, it can degrade the quality of the crops, both in appearance and taste, thereby reducing opportunities for crop exports, as well as the desirability of crops for local markets. Polluted water can even make some crops unfit for consumption, particularly if eaten raw.

Infrastructure. The West Bank and Gaza lack the infrastructure to supply water and to provide proper sanitation. The shortage of capital for new infrastructure and the destruction of existing infrastructure by Israeli forces have exacerbated the problem in recent years. The World Bank estimated the cost of the latest intifada's damage to the water infrastructure at $3.6 million, as of December 2001 (UNDP, 2002). Damage due to more recent conflicts has also been extensive.

Many communities do not have access to a centralized water supply or to sanitation. The Palestinian Hydrology Group's (PHG) ongoing survey of water consumption has so far found that a portion of the population in about 35 percent of communities has no, or almost no, water service. Earlier analyses estimated that roughly 200,000 Palestinians, or 200 communities, were without access to water networks (Naji, 1999; Lein, 2001). CH2M HILL (2002a) estimates that roughly 25 percent of the West Bank population is not currently connected to a piped water source. The Israeli Water Commission estimates this value to be 10 percent. In rural areas, the percentage of homes without a centralized water supply can exceed 60 percent.

Provision of sanitation services is even scarcer: More than half of the communities and 60 to 75 percent of Palestinians have no working sanitation system (Naji, 1999; PHG, 2003; Al-Sa'ed, 2000). In rural areas, almost all homes dispose of their waste in cesspits or open channels.

Closely related to poor infrastructure are losses in the delivery of water or unaccounted for water (UFW). UFW has two causes: physical losses, in which water disappears from the physical infrastructure; and commercial losses, in which water that is not being billed actually does reach water users (Saghir, Schiffler, and Woldu, 2000). Physical losses—mostly leaks, as well as some evaporation—usually account for a significant portion of total UFW. Such losses are caused by inadequate maintenance of pipes and other physical infrastructure, which is often due to institutional and financial weaknesses in public water utilities. Physical losses combined with intermittent supply also affect drinking water quality. Polluted water leaking from broken sewers or from cesspits can be pulled into water distribution pipes, as a result of substantial changes in pressure that occur when supplies are turned on and off (Saghir, Schiffler, and Woldu, 2000). Commercial losses can be due to illegal connections, malfunctioning meters, incorrect meter reading, and faulty billing. As in the case of physical losses, the basic causes for commercial losses are institutional and/or financial weakness of public urban water utilities. In some cases, the utility lacks the management resources to develop a reasonably efficient billing program. In other cases, financial constraints hinder the purchase of equipment and the hiring and training of personnel.

Around the world, water losses can be as low as 8 percent; less than 20 percent is considered adequate in a well-run utility. In the Middle East, losses can be as high as 50 to 60 percent. In the West Bank and Gaza, about 40 percent of all centrally provided water is lost in the conveyance system (Saghir, Schiffler, and Woldu, 2000). Leaks in the sewage system are also substantial and result in losses of approximately 30 percent of sewage conveyed (Naji, 1999).

Health Implications. Inadequate water availability and poor water quality have important health implications for Palestinians. In a recent PHG survey, more than one-fifth of all communities reported that at least 1 percent of the population had water-related health problems. Some communities reported that 17 percent of the population had water-related health problems (PHG, 2003).

Many acute and chronic health problems can be caused or exacerbated by poor water quality and exposure to untreated wastewater. Water scarcity and high salinity can result in kidney dysfunction or failure, which can be exacerbated by the hot weather common in this region (Bellisari, 1994). Chemicals, such as nitrates, found in the water supply cause other water-related illnesses, including diarrhea. The PHG survey found that more than 10 percent of children less than five years old were reported to have had diarrhea episodes during the two weeks previous to the survey. In addition, there are long-term health consequences of ingesting contaminants in the water. For example, high nitrate concentrations can increase anemia and induce spontaneous abortion (Bellisari, 1994). Exposure to raw sewage as a result of the lack of sewage infrastructure also has significant short- and long-term health implications, especially in such vulnerable populations as children and the elderly. Finally, communicable diseases such as hepatitis are "the most prevalent and most serious of all health problems associated with the water supply" (Bellisari, 1994).

Water for a Future Palestinian State: Policy Options

Immediate water issues must be addressed to protect the health and well-being of the West Bank and Gaza population. Current water quantity and quality are insufficient for the population and will not support population or economic growth. New water supplies and demand management need to be developed in parallel and in concert with the design of the water supply and waste systems.

Options for addressing future water scarcity and quality issues for the West Bank and Gaza follow.

Demand Management

Water demand growth can be moderated through sensible policies for managing domestic and agricultural demand and through infrastructure improvements. Improving domestic efficiency and implementing systems to reuse household wastewater from sinks and showers (i.e., graywater) are the two primary methods for reducing domestic demand without compromising water services. Improving irrigation efficiency, providing incentives to switch irrigation from water-intensive crops (such as fruit trees) to less-intensive crops (such as vegetables), and limiting irrigation growth are all effective methods for managing agricultural demand. Finally, reducing water losses from the supply infrastructure can reduce the required supply for both sectors.

Demand Drivers. It is impossible to predict precisely how the many factors driving today's domestic, industrial, and agricultural water demand will affect future demand. Although industrial and commercial demand today is very small, a future state will develop a stronger economy, with corresponding increases in demand for water. Domestic demand, a large component of today's total demand, is driven by two highly

uncertain factors—per-capita water consumption and population growth. Per-capita water consumption is currently constrained in most places by supply; more water would be consumed if it were made available at affordable prices. Per-capita consumption in those few municipalities with a reliable centralized water supply is largely determined by household needs, tempered by the cost of the water. This suggests that per-capita consumption will rise initially as supplies are increased. The second determinant, population growth, will be affected by both the internal growth rate in the population and the net inflow of Palestinians (returnees), which is difficult to predict.

The PWA ultimately would like to develop water resources so that supply can meet demand. For planning purposes, however, per-capita consumption targets must be set. The current long-term goal of the PWA is to increase water consumption to 150 l/d (CH2M HILL, 2002a). In the shorter term, we use the intermediate goals of increasing effective consumption to 100 l/d by 2015 and 120 l/d by 2020. As discussed below, investing in domestic water efficiency and graywater reuse can reduce the actual water delivery requirement below this level without affecting service to the consumer.

Demand for agricultural water is uncertain and is tempered by agricultural policies. Consumption depends on how much land is irrigated and the type of irrigation used. It also depends on the types of crops irrigated, and the needs of livestock. Options for managing agricultural demand include upgrading water delivery systems (e.g., lining canals) and improving and maintaining irrigation equipment. Limiting the expansion of irrigated agricultural area and encouraging the shift of irrigation away from water-intensive crops are other important demand-management policies.

Increasing Domestic Efficiency and Implementing Reuse of Graywater. Increased domestic efficiency and water reuse can reduce per-capita domestic consumption without compromising consumer services or public health. The efficiency of domestic consumption can be enhanced by installing water-efficient showerheads, toilets, and faucets. These relatively inexpensive devices can significantly reduce the water consumed by many household activities. A typical household connected to a water system can reduce water consumption by approximately 25 percent by adopting a complete suite of domestic efficiency technologies, including faucet aerators, low consumption showerheads, and low water-use toilets (CH2M HILL, 2002a). The estimated cost for implementing these measures is about $300 per household, with an annual maintenance cost of $30 (CH2M HILL, 2002a) (see the subsection Domestic Efficiency in this chapter for more details).

In addition, minor plumbing modifications can allow much of the graywater in a household to be reused. Possible graywater systems would filter water from sinks and showers and divert it for use in toilets; for washing clothes, windows, and vehicles; and for domestic irrigation. A household retrofitted with a domestic graywater reuse system (where shower and sink wastewater is filtered and reused for toilet flushing, clothes washing, and domestic irrigation) can reduce water use by 40 percent (Libhaber, 2003; Faruqui, 2002; Pottinger, 2003). Graywater reuse is often hindered by fears of negative

health outcomes. The graywater systems we propose, however, do not carry many of these health risks—the systems we propose do not reuse toilet water nor do they use graywater for personal hygiene or cooking (Faruqui and Al-Jayyousi, 2002). A case study in Jordan implemented a graywater reuse program in 50 homes and estimated the average annual costs of the graywater reuse system to be $113, which is deemed high because it includes one-time plumbing modifications (Faruqui and Al-Jayyousi, 2002). We used an estimated cost of implementing a graywater system that is about the same as the domestic efficiency measures—about $300 per household, with an annual maintenance cost of $30 (personal communication with Naser I. Faruqui, April 1, 2003; Faruqui and Al-Jayyousi, 2002).[7]

If a household implements both efficiency measures and graywater reuse, the long-term water supply and energy savings continue, since efficiency measures reduce the consumption of freshwater (for showering and cooking) and the consumption of graywater for toilet flushing.

The current insufficiency of domestic water supplies in the West Bank and Gaza has led to a high awareness of the need to use water efficiently and reuse water where possible. Although there is presently no centralized wastewater reuse, Palestinians out of necessity are highly efficient with provided supplies, and reuse water informally within the household. Given the need to reuse with little or no capital investment, many households simply place a bucket underneath the kitchen sink.[8] Once Palestinians are connected to a reliable centralized water supply, however, the incentives to reuse may be significantly reduced. As water service to Palestinians becomes more reliable, building efficiency and reuse into the system will be necessary to moderate water demand to levels appropriate to the available water resources in the region. Because Palestinians already reuse water informally, they are likely to better understand, accept, and support efficiency and reuse measures.

Improving end-use efficiency and ensuring adoption of decentralized reuse technologies will require up-front investments in equipment, information, and education, and will not be simple to implement. The West Bank and Gaza have a surplus of labor that can be trained to install and maintain small-scale water systems.[9] Consumer efficiency and reuse can reduce the total cost of water development and the cost borne by consumers while increasing the security of the water supply. Furthermore, unlike other options to deal with the limited water resources in the regions, extensive planning procedures are not needed prior to implementation. Consequently, these actions can affect demand in the near term.

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[7] We estimated a graywater system that included only simple filters, not treatment. These numbers are at the high end of the range of costs in the Jordan case study.

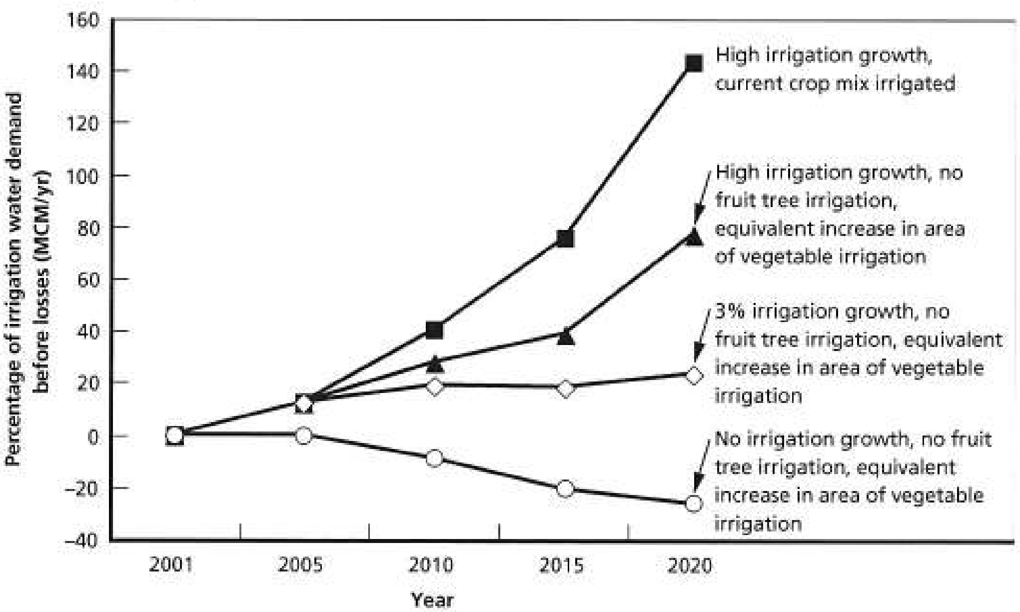
[8] Personal communication with Naser I. Faruqui, April 1, 2003.

[9] The training needs for such a workforce may require greater educational investment and thus lead to higher costs for implementing the efficiency and reuse policies.

Limiting Irrigation Growth and Improving Irrigation Efficiency. Increasing the efficiency of irrigation can temper growth in demand for agricultural water. Efficiency can be increased through investment in water-saving technologies such as drip irrigation systems. Drip irrigation is the predominant irrigation method used in the West Bank and currently is about 75 percent efficient. Rehabilitation and enhanced maintenance of these systems can increase efficiencies to 85 percent (CH2M HILL, 2002b). The improved application of irrigation systems will significantly reduce use not only of water, but also of fertilizer and pesticides, thereby reducing runoff and leaching problems.

Managing the growth of irrigation as well as encouraging a shift from water-intensive crops (such as fruit trees) to less-intensive crops (such as vegetables) can also control the agricultural water demand. To illustrate how future demand could vary, Figure 6.4 shows a wide range of future irrigation demands for different rates of irrigation expansion, with or without shifting all irrigated acreage from fruit to vegetables. Each line in the graph assumes different growth rates in irrigation with possible shifts in mixes of irrigation used for agriculture crops from higher-use fruit to lower-use vegetables. Depending on the growth rate and the crop mix, agricultural demand for water could grow more than 140 percent, or decline by over 20 percent by 2020.

Figure 6.4
Scenarios of Irrigation Water Demand for the West Bank and Gaza



NOTE: Strong growth corresponds to the following inter-period growth rates: 3.0 percent, 4.5 percent, 8.0 percent, and 7.0 percent.
RAND MG146-6.4

Supply Enhancement and Sustainability

In this subsection we briefly describe the major opportunities and requirements for sustainably supplying future Palestinian water demand.

Reducing Withdrawals from Aquifers. The Palestinians and the Israelis are collectively over-utilizing both the Mountain and Gaza Aquifers. Although negotiations between Israel and a future Palestinian state will ultimately determine the quantity of groundwater sustainably available to the Palestinians, it is certain that both the Palestinians and Israelis must reduce their withdrawals in order to retain the Gaza Aquifer as a viable water source. For the Mountain Aquifers, increased Palestinian use of groundwater supplies should be accompanied by concurrent reductions by Israel.

Harvesting Rainwater and Capturing Storm Water. Rainwater harvesting is an important source of water in the West Bank and, to a lesser extent, in Gaza. For many Palestinians, particularly in rural areas of the West Bank where no centralized water distribution system exists, rainwater capture is critical for meeting basic needs. Typically, residents divert rainwater into excavations in the ground (cisterns) and use this water throughout the dry season. Each cistern holds an average of 70 to 100 cubic meters, enough to satisfy minimal requirements during the rainy season and then for an additional three to four months during the dry season (Hunt, 2001). Between 50,000 and 80,000 cisterns in the West Bank currently augment supply (ARIJ, 1995, 1996; National Research Council, 1999; UNEP, 2001).

Investing in rainwater harvesting could supplement centralized water provision. Although installation of rainwater capture systems will be labor and capital intensive, especially in urban areas, increasing national capacity for capturing rainwater could augment by several times the current amount of rainwater captured. To ensure that this water source does not endanger human health, residents will need to be educated about cleaning and maintaining all components of the system. Ensuring the availability of efficient and decontaminated catchments and cisterns to supplement centralized distribution in rural and urban areas will require investments in equipment and education.

Capturing storm water could also augment Palestinian water supplies. Capture requires constructing single or multiple small dams on appropriate wadis. During periods of very heavy rainfall, these dams could provide flood control, as well as supply water for agricultural, industrial, or domestic uses or for aquifer recharge. CH2M HILL (2002a) estimates that up to 148 MCM/yr of storm water runoff is available for capture in the West Bank. The engineering and environmental costs would be high for an ambitious storm water program of this magnitude. As an alternative, CH2M HILL proposes projects that would capture 15 MCM/yr by 2015 and 28 MCM/yr by 2025. We use the latter proposal in the analysis below.

Reclaiming and Reusing Wastewater. Wastewater can be treated and reused to reduce the demands on limited water sources. Treated wastewater can be reused for domestic and agricultural irrigation, industrial uses, domestic toilet water, aquaculture,

environmental uses, and/or aquifer recharge. In the near term, agricultural reuse is the most promising of these options because public concern about the safety of treated wastewater for domestic consumption may be considerable.

In Israel, 70 percent of wastewater is already treated and reused for irrigation (National Research Council, 1999). Israel first began to reuse wastewater in the 1970s, primarily for its cotton crop (Juanicó, 2002). Today, reuse is integral to Israel's water management. In fact, Israel uses a higher percentage of wastewater for irrigation than any other country (Shelef, undated). The water reuse techniques that Israel has used so successfully could also be applied to the Palestinian agricultural sector.[10]

The current lack of infrastructure in the West Bank and Gaza provides a unique opportunity to build wastewater reuse into the infrastructure during initial construction. Ensuring wastewater treatment, while admittedly a major undertaking, is critical for protecting human health, current ground and surface water sources, and the environment. As a result, all wastewater in the West Bank and Gaza must be treated before discharge, regardless of whether it is reused. The marginal cost of providing treated wastewater for agricultural reuse, however, is small relative to the cost of initially building the wastewater collection and treatment infrastructure, and much smaller than retrofitting existing infrastructure.

Agriculture is currently the most attractive use of wastewater because (1) the standard of treatment required is lower than for other uses; (2) the nutrients in wastewater can benefit agriculture; and (3) public acceptance is relatively high. Although some wastewater is informally reused for agriculture near the three currently existing wastewater treatment plants in Gaza (Tubail, Al-Dadah, and Yassin, undated), no wastewater in Gaza or the West Bank is officially reused (National Research Council, 1999; CH2M HILL, 2001). CH2M HILL (2002a) reports that up to 85 percent of the municipal and industrial water supply could eventually be treated for use in agriculture. Because of the variation in irrigation demand relative to wastewater production, storage capacity may be required (National Research Council, 1999).

The municipal and industrial sector could also reuse treated wastewater, although it requires more treatment (to potable standards) and conveyance infrastructure than agricultural reuse. The large need for a potable water distribution network provides an opportunity to build dual distribution systems (separate distribution for potable water and reclaimed wastewater) at a cost relatively low compared with retrofitting a distribution system to accommodate dual uses (National Research Council, 1999). Theoretically, centralized wastewater reuse could provide as much as three-quarters of the annual municipal demand (National Research Council, 1999).

Because of current public apprehension about the safety of reusing wastewater, reusing it for irrigation is probably the most tenable option for the next ten years. However, as demand increases and Palestinian industries expand, acceptability and

[10] Reuse of treated wastewater must be restricted to the portion of the Palestinian agricultural sector that does not grow crops eaten raw (such as fresh fruit).

cost-effectiveness for non-agricultural uses are likely to increase. If reuse were limited to non-potable uses, the health risks would be insignificant.

Public education and appropriate water pricing could increase public acceptance of wastewater reuse. Use of treated wastewater is currently limited because of both a lack of infrastructure to treat and deliver wastewater to agricultural regions and the low cost of alternative sources of water supply for irrigation. For example, groundwater can be pumped at very low costs from the shallow aquifer in Gaza, and the tariff for surface water provided by the public irrigation system in the Jordan Valley is only $0.02/CM. Under these circumstances, there is little incentive to use reclaimed wastewater, with its associated risks (real and perceived) to health and the marketability of agricultural produce.

Desalination. Desalination is an energy-intensive technology that can produce great quantities of freshwater for use in any sector. Seawater desalinated and treated to potable standards can be supplied directly to the end user. Alternatively, desalinated water can be combined with lower-quality brackish water or contaminated groundwater to yield larger quantities of potable water. In fact, in Gaza, desalinated water with a salinity of 500 parts per million (ppm) is combined with brackish water with a salinity of about 3,000 ppm to yield a blend of potable water with a salinity of 1,500 ppm.[11] The result is a blended water source that can be provided at a lower cost than pure desalinated water.

The cost of desalinated water is high as a result of its high capital requirements and large energy costs. It is usually cost-effective only when surface water, groundwater, or imported supplies are not available. In the Middle East, where water is critically scarce, desalination may play a role in a prudent water management strategy. For Gaza, most analysts would agree that desalination is required to meet the needs of its population. In fact, desalination facilities are already planned in both Israel and Gaza. The Gaza plant, largely financed by the U.S. Agency for International Development, is projected to produce 20 MCM of water per year starting in late 2004 (U.S. Consulate General in Jerusalem, 2002). For the West Bank, desalination is one of several options for augmenting the water supply. Its desirability will largely depend upon its cost relative to other options and the security implications of the required transport of water from the Mediterranean to the West Bank.

A major determinant of the cost of desalinated water is the related energy requirement. Energy costs account for roughly one-third of desalination costs alone, and large amounts of energy would also be required to pump water from a desalination plant on the Mediterranean Sea to the West Bank. If the water is to be used for irrigation, investment and energy costs are lower than for producing potable water because higher salinity (and other contaminant) levels may be acceptable for some crops. Similarly, brackish water is less saline and, therefore, more cost-effective to desalinate than seawater. However, desalinating brackish water is still expensive ($0.50–$1/CM) and en-

[11] Personal communication with Alvin Newman, April 3, 2003.

ergy intensive, and the limited sources of brackish water constrain its usefulness as a source. We consider only seawater desalination in this analysis.

Thus, weighing desalination's costs against its benefits is highly dependent on traditional energy costs, the potential presence of renewable solar and wind energy, and the development of less energy-intensive technologies (Abraham, Owens, and Brunsdale, 1999). If the recently discovered natural gas reserves in the Mediterranean Sea can be developed, energy costs may be low enough to make desalination a widespread option. Reverse osmosis is currently the cheapest technology to desalinate water. It is the primary option considered in planning desalination plants.

The scenarios below consider desalination of Mediterranean seawater. We use the cost estimates of CH2M HILL (2002b) for a 50 MCM/yr reverse osmosis plant (~$1.06/CM). Although the operators of the recent Gaza desalination plant expect to produce desalinated water at about half this cost, these low costs have yet to be achieved in practice. If lower desalination costs are achievable in practice, the relative attractiveness of desalination as a new source of water for the region will increase. CH2M HILL suggests that the maximum feasible amount that could be brought on line by 2025 is roughly 390 MCM/yr. Although this option is especially important if groundwater rights are not reestablished, it does present a security risk. A pipeline would be needed to import desalinated water from the Mediterranean Sea, across Israel, and to the West Bank. As a result, large portions of the Palestinian supply would be vulnerable to sabotage and external control by Israel if tensions were to intensify. Although some of this risk could be mitigated through international guarantees or insurance, a high level of political stability is a prerequisite for this water supply option.

Infrastructure Improvements

Expanding Water and Wastewater Infrastructure. Building new water delivery and wastewater infrastructure is a high priority, and in our analysis we treat such infrastructure as a necessity rather than an option. Central provision of water and appropriate sewage services must be extended to the entire population in both the West Bank and Gaza. Transitioning toward a sanitation program is integral to reducing the degradation of aquifers and surface water bodies and eliminating the negative health consequences of unsanitary wastewater disposal. Similarly, transitioning to a central distribution network will eliminate the reliance of the poorest portions of the population on water tankers or degraded water bodies.

The dearth of existing infrastructure presents a unique opportunity to incorporate innovative ideas in water management into the construction of basic infrastructure. For example, expanding wastewater treatment capacity in Palestine will not only eliminate the hygiene and pollution problems associated with raw sewage disposal, but it will also provide a new source of reusable water.

Improving Infrastructure. Due to both the lack of maintenance and the current crisis, much of the crippled existing infrastructure will need to be repaired or rebuilt.

This will entail connecting the quarter of the population currently without access to a centralized water source, connecting most of the Palestinians to wastewater treatment facilities, and repairing the leaky distribution systems.

Currently, it is estimated that 40 percent of water delivered to domestic end users and to agricultural areas is lost (CH2M HILL, 2002b). UFW can be reduced by (1) eliminating illegal use and unmetered connections, (2) reducing errors in metering, and (3) repairing leaks in the distribution system. The first two measures will lead to more efficient water use as previously nonpaying users are charged for the water, and will increase revenues for the water districts. Rehabilitating water networks, locating and fixing system leaks, and lining or piping agricultural water conveyance facilities will be expensive but cost-effective in the long term, by extending the usable amount of each unit of water supply.

Transporting and Distributing Desalinated Water. As discussed below, desalination of water from the Mediterranean Sea may be required to meet the water demand in the West Bank. In this case, a national water carrier may also be required to convey these new large sources. The costs of this infrastructure are included in any scenarios that include desalination for the West Bank.

Another option is to pipe seawater from the Mediterranean Sea or Red Sea to the Dead Sea, where it would be desalinated and used for domestic and agricultural uses. An advantage of this option is that it could replace the need for building a desalination plant on the Mediterranean Sea while also halting the drop in the Dead Sea's water level and the associated negative environmental implications. We do not consider this option in our analysis because it would not likely be in place prior to 2020. However, it should be considered in longer-term plans. Energy costs associated with this plan would amount to 20 to 40 percent of the total cost for importation from both the Red and the Mediterranean Seas. The collocation of power generation and desalination facilities would increase efficiency. Because the Dead Sea is below sea level, hydroelectric power generation from the flow to the Dead Sea could be used to reduce the external energy requirements of the desalination. Such a plan, with desalination plant capacities between 100 and 800 MCM/yr, is estimated to cost between $2 billion and $7 billion (Abraham, Owens, and Brunsdale, 1999; National Research Council, 1999). A conduit to bring the seawater to the Dead Sea is estimated to cost between $1 billion and $5 billion. A conduit from the Mediterranean Sea would be less expensive than from the Red Sea and would have fewer environmental complications (Abraham, Owens, and Brunsdale, 1999). The capital cost of the desalination plant itself is estimated to range between $200 million and $1 billion, or $0.50 to $0.75/CM of plant capacity.

Water importation from other regions has also been discussed as a potential solution to the water crisis in the region. CH2M HILL conjectured that 3.5 MCM/day could be piped from Turkey to supply the water-scarce regions to the south, including the West Bank. Another option would be to import water from Turkey via large tankers or barges. The estimates of the capital costs associated with a pipeline are between

$5 billion and $30 billion, and the annual operation and maintenance costs are estimated at roughly $205 million. The annual costs, assuming approximately $21 billion total capital costs, are $1.07 per CM for capital and $0.16 per CM for operation and maintenance. We do not consider these options as they are currently more expensive than desalination and would require substantial international cooperation.

Modeling Future Water Demand and Supply for Palestine

Palestinian water managers face significant challenges in providing sufficient water supplies to increase domestic consumption to world health standards, to accommodate future population growth, and to support agricultural and industrial growth. Sustainable aquifer use by both Israelis and Palestinians will require cooperation and coordinated management. Failure to do so will degrade much of the Palestinian water supply, increase treatment costs, and decrease agricultural productivity. Increasing water demand must be both managed and met, requiring the development of new sources. Finally, the infrastructure must be upgraded to deliver fresh water to the growing Palestinian population and to collect, treat, and dispose of wastewater.

As described in the section above, Water for a Future Palestinian State: Policy Options, the international community and Palestinian water managers have a variety of options available to them to manage future water demand and develop supplies. Each option has unique costs, and many options have rising marginal costs.[12]

Ideally, Palestinian water managers with the help of the international community would simply choose the least expensive set of demand-managing and supply-enhancing policies that would meet projected future demands. The expected cost of implementing the policy, however, should not be the only consideration. Significant uncertainty surrounds estimates of future supply and demand, the effectiveness of policies, and the costs of policy actions. Some policies will be more robust to unexpected outcomes than others. Furthermore, there are other non-financial costs of different policies (e.g., agricultural impacts) that should be considered when choosing the optimal long-term water management strategy for the West Bank and Gaza.

We generate a few plausible scenarios of water demand and supply from 2001 through 2020, reflecting both uncertain parameters and different potential policies (see Table 6.4). For each scenario, we also estimate the implementation costs from 2005 through 2014 and discuss the implications of each combination of demand management and supply augmentation strategies.[13] Because many parameters driving wa-

[12] An example of a policy with rising marginal costs is reducing system water losses. Decreasing losses from 40 to 30 percent is likely to cost less than the reduction from 30 to 20 percent, because the first improvements will often be easier and less expensive than later ones.

[13] We report the costs from years 2005–2014 to conform to cost estimates in other chapters.

Table 6.4
Parameters and Policy Options Modeled and to Consider in Future Analyses

Uncertain Parameters	Policy Options
Modeled	Modeled
Population growth	Domestic efficiency (D)
Energy costs	Domestic graywater use (D)
	Irrigation growth limits (D)
To Consider	Irrigation efficiency (D)
Aquifer recharge and yield	Crop shifting (D)
Policy costs	Rainwater harvesting (S)
Commercial & industrial growth	Storm water capture (S)
	Wastewater reuse (S)
	Desalination (S)
	Increase water system efficiency (I)
	To Consider
	Israeli aquifer use
	Per-capita consumption

NOTE: D, S, and I indicate demand, supply, and infrastructure options, respectively.

ter demand, water supply, and total project cost are uncertain, we test our scenarios against alternative population growth rates and energy prices. This brief sensitivity analysis motivates the need to thoroughly evaluate water management proposals and identifies those management strategies that are robust to these uncertain parameters.

Modeling Mechanics

There are several major modeling steps in generating water scenarios for Palestine. First, future water demands must be forecast. The forecasted demand (from 2001 to 2020) will depend on uncertain parameters such as population growth, as well as policy choices such as the desired per-capita water availability and the amount of water efficiency investment. Next, water sources must be identified to meet this demand.

The first source considered is sustainable groundwater supply. The amount of sustainable groundwater available for Palestinian use is dependent upon aquifer recharge rates and yields and upon Israeli withdrawals. Although the apportionment of the aquifer between the Israelis and Palestinians ultimately needs to be negotiated between the two states, we describe one possible sharing scheme upon which all our scenarios are based.[14] Next, water sources that do not require desalination are specified for each scenario. Any remaining water demand is met by desalination.

[14] We anticipate that the chosen aquifer-sharing scheme may not be acceptable to one or both states. Since successful water management will require some investment in desalination for both states, deviations from the proposed sharing scheme simply will shift the relative amount of desalination required for each state.

To estimate the total project costs, we consider the cost of (1) all demand management policies, (2) acquiring water from all sources above the 2001 baseline amount, and (3) all additional infrastructure required for water provisioning and wastewater collection, treatment, and disposal. These cost calculations are based upon a modified version of the West Bank Water Management Analysis Tool developed by CH2M HILL (2002b). We describe the modifications in the Appendix section at the end of this chapter.

Demand

We estimate Palestinian water demand separately for municipal and industrial uses and agricultural purposes. Municipal and industrial demand is composed of domestic, public, and industrial demands, along with system losses. Agricultural water demand includes irrigation and livestock demand, as well as system losses.

Domestic demand is the product of the population and effective per-capita consumption, adjusted for system losses. Current policy guidelines suggest that the effective per-capita domestic consumption rate (the amount of water required to meet basic services without efficiency and reuse) must increase from current levels of about 55 liters per day to about 100 liters per day by 2015.[15] Implementation of domestic efficiency measures and graywater reuse will reduce these net water needs. We model efficiency and graywater policy options in terms of household adoption rates ranging from 0 percent to 90 percent. Public and industrial demands are estimated as a fixed percentage of domestic demand (see the subsection on Municipal and Industrial Demand in the Appendix section at the end of this chapter for details).[16]

Agricultural demand can be defined as the sum of irrigation and livestock demand and physical losses. For the West Bank, we model irrigation water demand by separating irrigation demand growth due to expansion of irrigated lands (assuming the same cropping pattern) and crop shifting away from water intensive fruits toward vegetables. We use PHG estimates of the 1999–2000 cropping and irrigation patterns as a base from PCBS (2003b). The expansion of irrigated land is specified as a percentage growth over each time period. We represent crop shifting by altering the fraction of irrigated land that is growing fruit versus vegetables. Because the water needs are lower for vegetables, crop shifting reduces demand for irrigation water per unit of irrigated area.

For the West Bank scenarios presented here, we started with the West Bank agricultural demand in 2001 and then gradually increased to 2015 to the amount of water that would be used for existing irrigated crops if there were no shortages or rationing. From 2015 through 2020, irrigation demand growth expands by a specified annual percentage rate. The total demand for irrigation water is then equal to the irrigated area times the net irrigation water requirement.

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[15] According to WHO, 100 l/d is the minimum water requirement for domestic uses for households with connections to a centralized water distribution system (Howard and Bartram, 2003).

[16] Public demand is estimated to be 6 percent of domestic demand for all time periods. Industrial demand increases from 7 percent in 2001 to 13 percent in 2015.

For Gaza, we model irrigation requirements independently of current cropping patterns. For our base case we assume that 2001 water use persists through 2020. For other scenarios, we vary the amount of water made available to irrigation as a function of groundwater use and available treated wastewater.

Livestock water demands make up a small fraction of total agricultural demand. Following CH2M HILL (2001), we assume they will grow from 2001 levels at an annual rate of 3 percent.

Supply

Once water demand is estimated for each time period, supply must be identified to meet this demand. The first new source we consider is new Palestinian aquifer withdrawals, within the renewable limits. For the Mountain Aquifers, we use CH2M HILL (2002a) estimates of renewable aquifer yield. For the Gaza Aquifer, we use the Oslo Accords recharge value as the sustainable yield (see Figure 6.3). Based on a specified schedule of aquifer use by Israel, we compute the Palestinian allocations such that all renewable groundwater is fully used.

Next, we consider sources that do not need desalination. The amount of water available from these sources is determined by the amount of investment in each source, constrained by natural and feasibility limits. Harvesting rainwater can provide additional water to municipalities and is modeled as the percentage of households installing and utilizing cisterns. Storm water capture projects, as described by CH2M HILL (2002b), will provide 15 MCM/yr by 2015. Next, water available to the agricultural sector for irrigation is augmented by treated wastewater. The percentage of sewage that receives additional treatment for irrigation is a policy parameter in our model.

Finally, any remaining demand is met by desalination.

Infrastructure

The model specifies that 90 percent of the population will have access to an improved water network by 2015. This will involve providing water connections to 15 percent of the current population and 90 percent of all future Palestinians. Existing losses to the water system are about 40 percent. We consider various repair schedules that would reduce these losses to as low as 25 percent. Finally, because of the environmental and health consequences of untreated wastewater, our model specifies that no raw wastewater is discharged. This is achieved by providing centralized sewage treatment for the majority of the population (80 percent for the West Bank and 100 percent for Gaza) and septic systems when connection to a central sewer system is infeasible.

Infrastructure requirements vary according to the water management policies used. All new supply options involve considerable infrastructure investment. Most notable is the requirement for a pipeline to transport desalinated water from the Mediterranean Sea to the West Bank.

Project Cost

We use the West Bank Water Management Model by CH2M HILL (2002b) and other sources documented in the Appendix section of this chapter to estimate the cost of

implementing all the components of a management strategy from 2005 through 2014. It is important to note that these costs are highly uncertain and are calculated primarily for comparison purposes.

The estimated unit costs for each policy measure for the West Bank (WB) (see Table 6.5) differ from CH2M HILL's estimates only with regard to: (1) rainwater harvesting, because of differences in collection area assumptions and United Nations Environmental Programme (UNEP) capital cost estimates; (2) septic systems and graywater reuse, which are not considered by CH2M HILL; and (3) desalination, because of different energy cost assumptions. While wastewater treatment costs appear different than CH2M HILL's estimates, we have simply separated its estimates into two categories—reuse and treatment.

Costs for Gaza were adopted from the West Bank costs and modified where appropriate. For example: (1) the average household size in Gaza is larger than in the West Bank, leading to lower domestic graywater reuse costs (per capita); and (2) the rainfall in Gaza is significantly less than the mean rainfall in the West Bank, resulting in less water available from rainwater harvesting and thus an increased cost per CM.

The model accounts for the costs of providing new water sources and improving infrastructure. It does not, however, account for reduced costs that arise from some of these investments. For example, graywater reuse and efficiency improvements will decrease the need to empty cesspits, eliminating annual pumping costs of $60 (Faruqui, 2002). Similarly, reuse for domestic agriculture in a pilot project in Jordan provided an additional source of income for households and/or a reduction in food costs totaling an average of about $300 per year, or 10 percent of the household income. Concurrently, the graywater reuse decreased the domestic water consumption by an average of 15 percent and, as a result, lowered water bills by 27 percent. The total net benefit to a household on average was roughly $400.[17] We do not include such cost reductions in our analysis.

Options for the Future

Our analytic methodology allows us to examine a broad range of policy alternatives for meeting future Palestinian water needs. In this section, we first describe several scenarios of demand and supply to 2020, reflecting different policy approaches. For each scenario, we estimate the total cost for the projects from 2005 through 2014 to correspond to the time horizon of the other chapters in this volume.[18] Next we test the sensitivity of these approaches to varying population growth rates and energy prices.

[17] Personal communication with Naser I. Faruqui, April 1, 2003.

[18] All total cost estimates are the net present value of the total costs over the planning period of 2005–2014. After 2014, costs will continue to accrue, as capital costs (such as infrastructure) are amortized over the typical life for the capital, and as operations and maintenance costs continue to be realized. A 5 percent discount rate is used for all net present value calculations.

Table 6.5
Capital, Operations, and Maintenance Costs for Water Management Activities for the Original CH2M HILL Model and the Model Used in This Analysis

	Capital Costs ($/CM)			Operations and Maintenance Costs ($/CM)			
Policy Action	CH2M HILL—WB	RAND—WB	RAND—Gaza	CH2M HILL—WB	RAND—WB	RAND—Gaza	Notes
Domestic efficiency	0.15	0.15	0.15	0.11	0.11	0.11	Assumes household consumption of 525 l/d.
Domestic graywater reuse	N.A.	0.11	0.09	N.A.	0.14	0.12	See subsection above on Increasing Domestic Efficiency and Implementing Reuse of Graywater. Differences between Gaza and WB estimates are based on household size differences.
Agriculture system efficiency/rehabilitation	0.21	0.21	0.21	0.08	0.08	0.08	Based on Nuwimeh (near Jericho) village replacement of an open canal with a distribution pipe network; average between Nuwimeh village and estimated WB average.
Irrigation application efficiency	0.00	0.00	0.00	0.38	0.38	0.38	Maintaining drip irrigation systems.
New wells	0.41	0.41	0.41	0.52	0.52	0.52	Costs vary by energy price.
Rainwater harvesting (cisterns)	0.70	0.98	1.95	0.21	0.43	0.86	The quantity collected in Gaza, because of low average rainfall, is estimated to be half of the quantity collected in WB cisterns.
Storm water	0.49, 0.61, 0.76	0.49, 0.61, 0.76	0.49, 0.61, 0.76	0.02, 0.02, 0.03	0.02, 0.02, 0.03	0.02, 0.02, 0.03	Costs for 50, 100, 150 MCM/yr, respectively, of water savings.
Desalination	0.23	0.23	0.23	0.84	0.83	0.83	Costs vary by energy price.
Wastewater reuse	Included in treatment	0.14	0.14	Included in treatment	0.04	0.04	CH2M HILL computes wastewater treatment and reuse together.

Table 6.5—Continued

Policy Action	Capital Costs ($/CM) CH2M HILL—WB	Capital Costs ($/CM) RAND—WB	Capital Costs ($/CM) RAND—Gaza	Operations and Maintenance Costs ($/CM) CH2M HILL—WB	Operations and Maintenance Costs ($/CM) RAND—WB	Operations and Maintenance Costs ($/CM) RAND—Gaza	Notes
Waste treatment (central)	1.09	0.95	0.95	0.76	0.72	0.72	See System Efficiency Improvements below. CH2M HILL computes wastewater treatment and reuse together. For our analysis, treatment is a given and the amount of reuse is a policy lever.
Waste treatment (septic)	N.A.	0.06	0.06	N.A.	0.05	0.05	See Wastewater Treatment below in the appendix.
System improvements	0.33, 0.42, 0.52	0.33, 0.42, 0.52	0.33, 0.42, 0.52	0.13, 0.16, 0.20	0.13, 0.16, 0.20	0.13, 0.16, 0.20	Costs for 50, 100, 150 MCM/yr, respectively, of water savings.
Distribution	0.17	0.17	0.17	0.02	0.02	0.02	
Transmission ($/CM/km)	0.0010	0.0010	0.0010	0.0002	0.0002	0.0002	Assuming 50 MCM/yr; per unit costs are lower if larger quantities are transmitted.
Pumping	0.0039	0.0039	0.0039	0.0003	0.0003	0.0003	$/CM per meter head.
Mediterranean to West Bank pipeline	0.11	0.11	0.11	0.57	0.57	0.57	

NOTE: N.A. is not applicable.

The Base Case

For the base case, we assume that the population will grow by 3.3 percent in the West Bank and by 4.2 percent in Gaza (Table 6.6).[19] We assume per-capita consumption to rise from 55 l/d to 100 l/d by 2015. Energy costs are expected to increase 1 percent per year, from $0.06/kilowatt-hour in 2001. These electricity costs were estimated by CH2M HILL (2002a) based on the average costs for high-energy users of the Israeli Electricity Corporation.

For the West Bank, we specify that agricultural water deliveries will increase from the current suboptimal levels (see above subsection Demand Management) to optimal levels by 2015, holding the irrigated area constant. Thereafter the irrigated area is specified to grow by 3 percent/year. For Gaza, we specify constant agricultural water use through the modeling period.

The base case policy actions to manage demand and increase supply are conservative. System improvements to reduce losses, domestic efficiency improvements, and cistern expansion are all modest, and no domestic graywater systems are employed. Twenty percent of wastewater is treated and reused for irrigation.

For the base case, we project total water demand in the West Bank to increase from the 2001 amount of 122 MCM/yr to 340 MCM/yr by 2015 and to approximately 422 MCM/yr by 2020 (Figure 6.5). This strong demand growth is driven by both the municipal and industrial (M&I) and agricultural sectors. In Gaza, total water

Table 6.6
Base Case Scenario Model Parameters

	West Bank		Gaza	
Policy	**2001**	**2015**	**2001**	**2015**
Population growth	3.3% / year		4.2% / year	
Per-capita water consumption (l/d)	55	100	55	100
Energy costs	1% / year		1% / year	
Agricultural irrigation growth	Optimal by 2015		Constant	
Water system losses	40%	29%	40%	29%
Households adopting efficiency measures	0%	12%	0%	12%
Households adopting graywater systems	0%	0%	0%	0%
Households utilizing cisterns	25.5%	35%	25.5%	35%
Percentage of wastewater used for agriculture	0%	20%	0%	20%
Storm water capture (MCM/yr)	0	15	0	0

[19] The 2001 population in the West Bank and Gaza is set to 2.11 million and 1.20 million, respectively, according to PCBS population estimates (2003a). Annual population growth rates are estimated from PCBS "medium projections" for the time period between 2000 and 2020 (see Chapter Four of this book, Table 4.4).